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Volatile Organic Compounds in Foods: A Five Year Study

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A purge and trap procedure was used with gas chromatography–mass spectrometry determination to analyze 70 foods for volatile organic compounds (VOCs). The results from analyses over a 5 year period (1996–2000) are reported. VOCs were found in at least one sample of all foods tested, although no single compound was found in each of the foods. The total amount of VOCs found in a single food item over the 5 year period ranged from 24 to 5328 ppb, with creamed corn (canned) the lowest and cheddar cheese the highest. Benzene was found in all foods except American cheese and vanilla ice cream. Benzene levels ranged from 1 to 190 ppb, with the highest level found in fully cooked ground beef. Benzene was found in 12 samples of cooked ground beef, with an average of 40 ppb. Benzene levels above 100 ppb were also seen in at least one sample each of a cola (138 ppb), raw bananas (132 ppb), and cole slaw (102 ppb). This compares to a maximum contaminant level of 5 ppb set by the U.S. EPA for drinking water.

KEYWORDS: Volatile organic compound (VOC); gas chromatography–mass spectrometry (GC-MS); food analysis

INTRODUCTION

The U.S. Food and Drug Administration (FDA) monitors the concentration of residues of pesticides, industrial chemicals, metals, nutrients, and volatile organic chemicals (VOCs) in the nation's food supply. In the Total Diet Program, selected foods are purchased from supermarkets throughout the United States. Collections are made four times a year and on a regional basis. That is, 5 years of study equals 20 analytical sets. The foods are rendered table ready by being prepared as they would be in a domestic kitchen. The items selected by FDA are based on surveys of food consumption habits published and periodically updated by the U.S. Department of Agriculture (*1–3*).

VOCs are a group of low molecular weight aliphatic and aromatic compounds with low boiling points. Sources of VOCs include solvents, dry cleaning compounds, degreasers, paints, chemical intermediates, and assorted industrial products. They are also products of combustion and the chlorination of drinking water (*4*). Additionally, VOCs can come from the process of microwaving foods (*5*). Some VOCs are even allowed as indirect food additives from components of commercial packaging (*6*).

A method based on purge and trap extraction and gas chromatography–mass spectrometry (GC-MS) detection was developed for determining VOCs in table ready foods (*7*). This technique was previously developed to determine VOCs in cheese and bacterial cell suspensions (*8*, *9*). Food samples are chopped or blended, weighed, and heated in antifoam-treated deionized water in a boiling water bath and then purged with helium to volatilize the analytes. The analytes are collected on a Vocarb 3000 trap, thermally desorbed, and cryofocused on a capillary DB-624 column and then quantified by injection into a GC-MS. This method was validated by verifying the recovery of 27 of the volatile compounds (EPA method 524.2) that were spiked into table ready foods (*1*). This paper presents the results of 5 years of testing 70 table ready foods using the previously described method.

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MATERIALS AND METHODS

Sample Preparation. Foods that are normally cooked (e.g., meats and vegetables) were cooked as they would be in a domestic kitchen. Fast foods (chicken nuggets, cheeseburger, French fries, and pizza) were obtained ready-to-eat. Samples were prepared as described in detail (*7*). Briefly, solid food samples were chopped or blended and frozen prior to analysis. Liquid samples and baby foods were used as received from a supermarket. A 10 g sample aliquot along with 250 mL of purified antifoam-treated deionized water was placed in a 500 mL two-necked round bottom flask fitted with a Vocarb 3000 adsorption trap in one opening and a helium gas sparger in the other. One milliliter of internal standard (consisting of 50 ppb each of 1,2-dichloroethane-d_4, toluene-d_8, and *p*-bromofluorobenzene) solution was added to each flask, and the flask was placed in a boiling water bath for 30 min. The sample/water mixture was stirred vigorously using a magnetic stirring bar, and helium was purged through the flask at 25 mL/min with rapid stirring to obtain a strong vortex. After 30 min, the adsorption tube was removed and analyzed by GC-MS.

Thermal Desorption GC-MS. The Vocarb adsorption tubes were analyzed by GC-MS using a Tekmar 6000 thermal desorber with 6016 autosampler and a Varian 3400 GC interfaced to a Saturn II ion trap mass spectrometer as described previously (*7*).

RESULTS AND DISCUSSION

VOCs were found in all foods tested, although no single compound was found in each of the foods. VOCs ranged from

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Table 1. Foods Analyzed for VOCs

whole milk	sweet rolls
American cheese	chocolate chip cookies
cheddar cheese	sandwich cookies
ground beef	apple pie
chuck roast	milk chocolate candy bar
bacon	caramels
hot dogs	cola
bologna	low calorie cola
salami	milk-based infant formula
tuna	beef, strained/junior
fish sticks	carrots, strained/junior
eggs, scrambled	apple juice, strained/junior
peanut butter	Swiss cheese
corn, cream style	cream cheese
popcorn	chicken nuggets
white bread	fried chicken, fast food
blueberry muffins	mixed nuts
corn chips	graham crackers
fruit-flavored cereal	butter crackers
apples	french fries, fast food
oranges	quarter pounder/cheese
bananas	taco/tostado
strawberries	cheese pizza
raisins	cheese/pepperoni pizza
avocados	vanilla ice cream
orange juice	sherbet
coleslaw	popsicles
tomatoes, raw	chocolate snack cake
potato chips	cake doughnuts
quarter pounder	brownies
meatloaf, homemade	sugar cookies
margarine	sour cream
butter	olive/safflower oil
vanilla ice milk	fruit-flavored drink
chocolate cake, commercial	soy-based infant formula

Table 2. List of 27 VOCs Looked for in Foods

benzene	1,2-dichloroethene, *trans-*
bromobenzene	1,2-dichloropropane
bromodichloromethane	ethyl benzene
butylbenzene, *n-*	ethylene dichloride
carbon tetrachloride	propylbenzene, *n-*
chlorobenzene	styrene
chloroform	tetrachloroethylene
chlorotoluene, *o-*	toluene
chlorotoluene, *p-*	1,1,1-trichloroethane
cumene	trichloroethylene
dichlorobenzene, *o-*	1,2,4-trimethylbenzene
dichlorobenzene, *p-*	xylene, *m-* and/or *p-*
1,2-dichloroethene, *cis-*	xylene, *o-*

24 to 5328 ppb, with creamed corn (canned) the lowest and cheddar cheese the highest. The 70 different foods analyzed are presented in **Table 1**. The 27 VOCs that were looked for are listed in **Table 2**.Two of them, *m-* and *p*-xylene, were not separated and are reported as *m-* and/or *p*-xylene. Five of them, bromobenzene, *o-* and *p*-chlorootoluene, *cis*-1,2-dichloroethene, and 1,2-dichloropropane, were not found in any of the samples. The compounds found in 41 of these foods, together with the number of findings and the minimum and maximum values found are in **Table 3**. The foods included in this table had at least 100 ppb of a VOC. The 29 foods not included in **Table 3** had no single VOC over 100 ppb. Benzene was found in all foods except American cheese and vanilla ice cream. Benzene levels were 1−190 ppb, with the highest level found in fully cooked ground beef. The lowest (1 ppb) was in milk-based infant formula and raw strawberries. Benzene was found in 12 samples of ground beef, with an average of 40 ppb. Benzene levels above 100 ppb were also seen in at least one sample each of a cola (138 ppb), raw bananas (132 ppb), and cole slaw with dressing (102 ppb). This compares to a maximum contaminant level of 5 ppb set by the U.S. EPA for drinking water. The presence of benzene in so many foods reflects the ubiquitous nature of benzene in our industrial environment. For example, the smoke inhaled in an average cigarette contains about 40 μg of benzene, and refueling a car without stage II vapor recovery can cause an exposure to an estimated 20 μg (*10*). One would have to eat 10 kg of bananas containing 40 ppb benzene to reach a dose of 40 μg. Driving a car can cause the absorption of 20−30 μg/h, and breathing street side city air can cause 25 μg/h (*9*). The average daily dose from diet has been estimated to be 5 μg (*10*). A banana weighing ~200 g and containing 40 ppb benzene would contribute 0.8 μg.

Benzene is a human carcinogen and neurotoxin (*12−14*). Other VOCs reported to be human neurotoxins include 1,1,1-trichloroethane, styrene, toluene, trichloroethylene, and xylene (*14*). However, the doses needed to cause neurotoxicity are far greater than those detected in foods in this study. For example, drowsiness, dizziness, headache, vertigo, tremor, delirium, and loss of consciousness were reported after acute exposure to 300−3000 ppm of benzene vapors (*15*). This corresponds to 1000−10000 mg/m^3. The average human air intake is 20 m^3/day (*16*), so the exposure to benzene was 20 000−200 000 mg/day or 20−200 g/day. For acute exposure, this amount would be inhaled for only one 8 h work day at a time. However, in another report, 121 workers were exposed to 6−15 ppm (20−50 mg/m^3) of benzene vapors for 2−9 years, and 74 of them complained of frequent headaches, difficulty sleeping, and memory loss (*17*).

Other VOCs can be neurotoxic. Men exposed to 52−117 ppm of styrene in a boat-building factory were subject to mood changes, were more likely to report feeling tired, and had slower reaction times than unexposed workers (*18*). For 1,1,1-trichloroethane, the lowest observed adverse effect limit (LOAEL) for neurotoxicity was estimated to be 175 ppm (*19*). The LOAEL for toluene was estimated to be 100 ppm (*20*). For inhalation of xylenes, a maximum recommended level of 0.1 ppm was derived, based on subjective reports by workers in China, who were exposed in a factory for an average of 7 years (*21*).

Partly because of its heavy industrial production and use, there have been many reports on the toxicity of benzene in humans and other animals (*22−24*). However, benzene toxicity, like that of other VOCs, is almost always associated with inhalation of vapors with some unidentified contribution due to absorption through the skin (*24*). All other toxicities are probably caused by inhalation alone. The amounts needed to cause these toxicities are much higher than those found in foods in this study. For all toxicities except carcinogenesis, a threshold approach is often used, which sets acceptable daily intake levels (*25*). However, it is sometimes stated that a nonthreshold approach is used for potential carcinogens and that a single molecular adduct can initiate the multistep process of carcinogenesis (*24*). There is no detectable threshold for radiation-induced DNA damage. However, the threshold approach has been used to set regulatory levels for the known human carcinogen, aflatoxin (*26*).

The amounts of other VOCs found in foods are far below the amounts required to be toxic. For example, about 0.1 ppb styrene has been reported in fruits and vegetables, cooked pork, chicken, fish, mussels, and eggs (*27−34*), but 100 ppb was found in sausage from Turkey (*35*). The main source of public exposure to oral doses of styrene was estimated to be from its migration from polymer packaging materials (*36*). The amount migrated increased with the fat content of the food because of

Table 3. Results of VOCs Found in Food Items with over 100 ppb of a VOC[a]

VOC	N+	min (ppb)	max (ppb)	VOC	N+	min (ppb)	max (ppb)
			American cheese				
chloroform	12	11	54	toluene	11	17	255
xylene, *o*-	3	3	4	ethyl benzene	2	3	4
dichlorobenzene, p-	3	3	3	bromodichloromethane	1	3	3
1,1,1-trichloroethane	2	2	25	1,2,4-trimethylbenzene	1	6	6
trichloroethylene	1	2	2	xylene, *m*- and/or *p*-	11	4	112
styrene	4	2	11				
			cheddar cheese				
chloroform	12	3	107	benzene	2	20	47
dichlorobenzene, *p*-	1	2	2	ethyl benzene	1	12	12
1,1,1-trichloroethane	3	3	28	1-dichloroethene, *trans*-	3	10	24
tetrachloroethylene	1	8	8	1,2,4-trimethylbenzene	1	11	11
trichloroethylene	1	2	2	chlorobenzene	7	3	3
styrene	3	4	70	xylene, *m*- and/or *p*-	7	5	43
toluene	13	7	1300				
			mixed nuts				
chloroform	3	4	5	toluene	14	23	518
xylene, *o*-	8	4	25	benzene	3	1	6
dichlorobenzene, *p*-	2	2	9	cumene	2	3	6
1,1,1-trichloroethane	2	3	7	ethyl benzene	7	3	38
tetrachloroethylene	4	9	54	1,2,4-trimethylbenzene	10	11	98
trichloroethylene	2	2	5	xylene, *m*- and/or *p*-	8	8	107
styrene	14	21	104				
			ground beef				
chloroform	2	2	6	styrene	6	4	13
sylene, *o*-	2	3	3	toluene	13	10	40
dichlorobenzene, *p*-	2	9	127	benzene	12	9	190
chlorotoluene, *o*-	1	11	11	ethyl benzene	1	2	2
1,1,1-trichloroethane	1	3	3	1,2,4-trimethylbenzene	1	4	4
tetrachloroethylene	2	5	6	xylene, *m*- and/or *p*-	4	2	7
trichloroethylene	2	3	6				
			pork bacon				
chloroform	3	2	12	toluene	14	12	230
xylene, *o*-	1	2	2	benzene	6	2	17
dichlorobenzene, *p*-	2	4	8	ethyl benzene	1	2	2
1,1,1-trichloroethane	2	3	24	1,2,4-trimethylbenzene	7	7	80
styrene	7	6	85	xylene, *m*- and/or *p*-	5	3	25
			banana, raw				
chloroform	1	8	8	toluene	4	5	36
trichloroethylene	1	2	2	benzene	13	11	132
			cream cheese				
chloroform	13	38	100	styrene	2	2	3
1,1,1-trichloroethane	1	27	27	toluene	11	11	42
tetrachloroethylene	1	5	5	benzene	3	1	17
trichloroethylene	2	2	3				
			frankfurters, beef				
carbon tetrachloride	2	4	11	toluene	14	15	78
chloroform	6	3	14	benzene	4	2	11
xylene, *o*-	4	4	6	ethyl benzene	3	3	4
1,1,1-trichloroethane	1	3	3	bromodichloromethane	2	4	5
tetrachloroethylene	3	2	60	butylbenzene, *n*-	4	3	547
trichloroethylene	5	2	105	propylbenzene, *n*-	1	10	10
styrene	8	4	77	xylene, *m*- and/or *p*-	5	13	32
			chocolate cake with icing				
chloroform	5	3	16	benzene	2	2	23
xylene, *o*-	5	2	13	cumene	2	3	4
dichlorobenzene, *o*-	5	3	69	ethyl benzene	5	2	13
tetrachloroethylene	5	3	32	1,2,4-trimethylbenzene	8	11	150
dichlorobenzene, o-	1	5	5	butylbenzene, *n*-	1	5	5
trichloroethylene	3	3	57	chlorobenzene	2	2	3
styrene	12	7	57	xylene, *m*- and/or *p*-	8	7	41
toluene	14	14	227				
			tuna, canned in oil				
carbon tetrachloride	1	4	4	styrene	1	2	2
chloroform	2	4	4	toluene	10	5	790
xylene, *o*-	2	2	2	benzene	7	4	13
dichlorobenzene, *p*-	1	4	4	1,2,4-trimethylbenzene	1	4	4
1,1,1-trichloroethane	1	3	3	propylbenzene, *n*-	1	18	18
trichloroethylene	2	9	11	xylene, *m*- and/or *p*-	3	2	7

Table 3 (Continued)

VOC	N+	min (ppb)	max (ppb)	VOC	N+	min (ppb)	max (ppb)
			fruit-flavored cereal				
ethylene dichloride	8	16	144	toluene	6	3	140
chloroform	1	2	2	benzene	5	2	21
trichloroethylene	1	3	3	cumene	1	4	4
styrene	3	2	10	xylene, *m*- and/or *p*-	3	4	7
			eggs, scrambled				
chloroform	3	5	13	cumene	2	4	5
dichlorobenzene, *p*-	1	7	7	ethyl benzene	1	5	5
tetrachloroethylene	1	3	3	1,2,4-trimethylbenzene	1	13	13
styrene	6	5	10		1	13	13
toluene	8	4	100	xylene, *m*- and/or *p*-	2	2	4
benzene	4	2	40				
			peanut butter				
chloroform	3	2	8	toluene	13	24	62
xylene, *o*-	4	2	11	benzene	5	2	25
dichlorobenzene, *p*-	1	7	7	ethylbenzene	6	4	10
1,1,1-trichloroethane	6	3	51	1,2,4-trimethylbenzene	8	5	165
tetrachloroethylene	1	7	7	butylbenzene, *n*-	1	3	3
trichloroethylene	3	4	70	propylbenzene, *n*-	1	7	7
styrene	13	16	38	xylene, *m*- and/or *p*-	6	3	28
			avocado, raw				
chloroform	5	3	15	styrene	8	3	550
dichlorobenzene, *p*-	1	10	10	toluene	3	2	3
tetrachloroethylene	3	5	12	benzene	10	3	30
trichloroethylene	6	2	75	xylene, *m*- and/or *p*-		5	5
			popcorn, popped in oil				
chloroform	2	2	15	toluene	12	11	65
xylene, *o*-	1	2	2	benzene	3	4	22
dichlorobenzene, *p*-	2	67	292	bromodichloromethane	1	5	5
1,1,1-trichloroethane	3	4	27	1,2,4-trimethylbenzene	4	5	14
trichloroethylene	2	4	8	butylbenzene, *n*-	1	6	6
styrene	3	2	2	xylene, *m*- and/or *p*-	5	3	24
			blueberry muffin				
chloroform	3	8	15	styrene	10	8	141
xylene, *o*-	6	10	19	toluene	14	8	456
dichlorobenzene, *p*-	2	10	102	benzene	3	3	8
1,1,1-trichloroethane	1	3	3	cumene	1	2	2
tetrachloroethylene	3	3	27	ethyl benzene	4	3	101
dichlorobenzene, *o*-	1	36	36	1,2,4-trimethylbenzene	7	5	24
trichloroethylene	2	3	4	xylene, *m*- and/or *p*-	7	3	66
			strawberries, raw				
tetrachloroethylene	1	5	5	toluene	1	16	16
styrene	9	12	350	benzene	1	1	1
			cola, carbonated beverage				
chloroform	6	11	27	bromodichloromethane	2	3	3
benzene	3	1	138	chlorobenzene	1	5	5
			orange, raw				
chloroform	2	4	6	toluene	5	2	183
trichloroethylene	1	2	2	benzene	2	11	15
styrene	2	2	3	xylene, *m*- and/or *p*-	3	11	66
			coleslaw with dressing				
dichlorobenzene, *p*-	1	31	31	toluene	3	3	16
trichloroethylene	1	3	3	benzene	14	11	102
styrene	1	2	2				
			sweet roll/ danish				
chloroform	2	2	3	benzene	1	3	3
xylene, *o*-	2	4	5	cumene	2	7	25
1,1,1-trichloroethane	1	3	3	ethyl benzene	3	2	5
tetrachloroethylene	3	8	12	1,2,4-trimethylbenzene	6	16	187
trichloroethylene	3	3	4	xylene, *m*- and/or *p*-	5	4	29
styrene	13	13	91	chloroform	3	3	12
toluene	12	10	145	xylene, *o*-	2	2	18
			potato chips				
chloroform	3	3	12	toluene	12	11	162
xylene, *o*-	2	2	18	benzene	2	2	7
1,1,1-trichloroethane	4	3	10	ethyl benzene	2	2	11
tetrachloroethylene	1	7	7	1,2,4-trimethylbenzene	8	4	44
trichloroethylene	4	4	140	butylbenzene, *n*-	1	3	3
styrene	6	2	16	xylene, *m*- and/or *p*-	5	2	65

Table 3 (Continued)

VOC	N+	min (ppb)	max (ppb)	VOC	N+	min (ppb)	max (ppb)
			fruit-flavored sherbet				
chloroform	5	0	27	ethyl benzene		3	3
toluene	10	9	203	bromodichloromethane	1	3	3
benzene	3	3	61	xylene, *m*- and/or *p*-	5	3	65
			popsicle				
chloroform	6	6	18	benzene	4	1	10
styrene	3	4	11	bromodichloromethane	1	3	3
toluene	5	1	36	1,2,4-trimethylbenzene	1	168	168
			quarter pound hamburger, cooked				
chloroform	4	2	14	toluene	14	10	180
xylene, *o*-	3	3	3	benzene	11	4	47
1,1,1-trichloroethane	2	3	19	ethyl benzene	3	2	3
tetrachloroethylene	1	38	38	bromodichlormethane	1	37	37
trichloroethylene	2	5	9	xylene, *m*- and/or *p*-	4	2	7
styrene	6	4	27				
			margarine				
chloroform	3	7	14	toluene	14	11	272
xylene, *o*-	6	2	12	benzene	1	7	7
dichlorobenzene, *o*-	6	3	208	cumene	3	2	5
1,1,1-trichloroethane	2	3	14	ethyl benzene	6	3	11
tetrachloroethylene	6	3	42	1,2,4-trimethylbenzene	8	4	60
trichloroethylene	3	2	21	propylbenzene, *n*-	1	8	8
styrene	10	9	20	xylene, *m*- and/or *p*-	10	8	44
			sandwich cookies				
carbon tetrachloride	1	11	11	toluene	9	5	130
chloroform	3	2	4	benzene	3	1	39
1,1,1-trichloroethane	1	3	3	1,2,4-trimethylbenzene	4	8	170
styrene	14	15	165				
			butter				
chloroform	14	35	83	benzene	6	4	22
xylene, *o*-	8	6	15	cumene	4	3	8
dichlorobenzene, *o*-	3	13	95	ethyl benzene	7	7	14
1,1,1-trichloroethane	3	7	23	1,2,4-trimethylbenzene	9	10	42
	8	11	102	butylbenzene, *n*-	1	3	3
trichloroethylene	2	7	9	propylbenzene, *n*-	3	3	6
styrene	12	11	28	xylene, *m*- and/or *p*-	11	21	59
toluene	14	30	148				
			chocolate chip cookies				
chloroform	2	3	4	benzene	2	1	8
xylene, *o*-	4	2	12	cumene	2	14	15
dichlorobenzene	4	8	37	ethyl benzene	3	2	11
1,1,1-trichloroethane	1	3	3	1,2,4-trimethylbenzene	12	7	81
tetrachloroethylene	4	2	18	xylene, *m*- and/or *p*-	5	4	25
trichloroethylene	2	2	4	chlorobenzene	1	2	2
styrene	12	15	111	xylene, *m*- and/or *p*-	4	3	14
toluene	14	12	248				
			sour cream				
chloroform	12	14	176	toluene	4	2	18
dichlorobenzene, *p*-	1	2	2	benzene	2	3	15
tetrachloroethylene	1	7	7	bromodichlorobenzene	1	4	4
styrene	3	5	30	chlorobenzene	1	2	2
			apple pie, fresh/frozen				
chloroform	3	9	19	toluene	7	4	25
xylene, *o*-	5	3	38	benzene	4	2	11
dichlorobenzene, *p*-	2	35	169	cumene	3	4	22
1,1,1-trichloroethane	1	3	3	ethyl benzene	5	2	14
tetrachloroethylene	5	3	52	1,2,4-trimethylbenzene	9	14	102
trichloroethylene	2	2	4	butylbenzene, *n*-	1	8	8
styrene	9	10	40	xylene, *m*- and/or *p*-	7	6	77
			chicken nuggets, fast food				
chloroform	4	2	16	benzene	4	2	5
xylene, *o*-	5	2	10	cumene	6	7	17
chlorotoluene, *o*-	1	13	13	ethyl benzene	5	2	23
1,1,1-trichloroethane	2	3	4	bromodichloromethane	1	3	3
tetrachloroethylene	2	2	7	butylbenzene, *n*-	1	10	10
trichloroethylene	3	2	5	propylbenzene, *n*-	1	4	4
styrene	12	10	66	xylene, *m*- and/or *p*-	5	5	40
toluene	14	10	230				

Table 3 (Continued)

VOC	N+	min (ppb)	max (ppb)	VOC	N+	min (ppb)	max (ppb)
			graham crackers				
chloroform	2	5	12	benzene	2	1	9
xylene, *o*-	2	2	11	cumene	1	2	2
dichlorobenzene, *p*-	4	3	50	ethyl benzene	2	6	23
1,1,1-trichloroethane	1	3	3	1,2,4-trimethylbenzene	9	7	86
tetrachloroethylene	2	2	5	butylbenzene, *n*-	1	3	3
dichlorobenzene, *o*-	1	2	2	propylbenzene, *n*-	1	4	4
styrene	6	4	21	xylene, *m*- and/or *p*-	5	3	50
toluene	12	10	109				
			french fries, fast food				
chloroform	2	2	3	cumene	2	2	10
xylene, *o*-	4	2	8	ethyl benzene	4	2	5
1,1,1-trichloroethane	1	3	3	bromodichloromethane	1	3	3
tetrachloroethylene	1	8	8	1,2,4-trimethylbenzene	8	8	72
dichlorobenzene, *o*-	1	11	11	butylbenzene, *n*-	1	3	3
trichloroethylene	2	3	3	chlorobenzene	2	4	13
styrene	12	8	68	propylbenzene, *n*-	1	3	3
toluene	11	22	165	xylene, *m*- and/or *p*-	4	5	22
benzene	3	2	58				
			cheeseburger, quarter pound				
chloroform	3	2	15	toluene	14	12	190
xylene, *o*-	3	2	4	benzene	8	5	44
1,1,1-trichloroethane	1	3	3	ethyl benzene	3	2	3
tetrachloroethylene	1	40	40	butylbenzene, *n*-	1	4	4
trichloroethylene	1	7	7	xylene, *m*- and/or *p*-	5	2	22
styrene	5	5	22				
			cheese pizza				
chloroform	3	3	11	toluene	13	12	253
xylene, *o*-	3	2	3	benzene	2	1	2
1,1,1-trichloroethane	1	3	3	cumene	3	9	15
tetrachloroethylene	1	16	16	ethyl benzene	1	3	3
trichloroethylene	1	2	2	1,2,4-trimethylbenzene	1	51	51
styrene	6	3	23	xylene, *m*- and/or *p*-	6	4	27
			bologna				
carbon tetrachloride	1	5	5	styrene	7	2	78
chloroform	3	5	15	toluene	14	10	77
xylene, *o*-	3	2	7	benzene	4	2	44
1,1,1-trichloroethane	2	10	18	ethyl benzene	2	2	4
tetrachloroethylene	7	2	27	butylbenzene, *n*-	2	4	410
trichloroethylene	5	2	20	xylene, *m*- and/or *p*-	4	5	9
			cheese and pepperoni pizza				
chloroform	3	2	6	toluene	13	13	310
xylene, *o*-	5	2	14	benzene	4	8	30
1,1,1-trichloroethane	1	3	3	cumene	1	8	8
tetrachloroethylene	1	19	19	ethyl benzene	3	2	3
trichloroethylene	2	2	2	chlorobenzene	1	2	2
styrene	7	8	20	xylene, *m*- and/or *p*-	8	6	42
			olive/safflower oil				
chloroform	1	4	4	benzene	6	1	46
xylene, *o*-	3	6	23	ethyl benzene	2	4	23
tetrachloroethylene	1	7	7	1,2,4-trimethylbenzene	3	8	49
styrene	11	3	54	xylene, *m*- and/or *p*-	6	2	110
toluene	7	6	32				
			sugar cookies				
chloroform	2	3	10	benzene	3	8	30
xylene, *o*-	2	3	5	ethyl benzene	2	2	5
dichlorobenzene, *p*-	2	2	29	1,2,4-trimethylbenzene	4	20	170
1,1,1-trichloroethane	1	3	3	butylbenzene, *n*-	2	3	19
tetrachloroethylene	3	5	35	chlorobenzene	2	2	3
styrene	14	24	142	propylbenzene, *n*-	1	5	5
toluene	9	6	292	xylene, *m*- and/or *p*-	5	2	21
			cake doughnuts with icing				
chloroform	2	2	6	benzene	2	3	3
xylene, *o*-	5	2	11	cumene	2	7	27
chlorotoluene, *o*-	1	11	11	ethyl benzene	4	3	14
1,1,1-trichloroethane	1	3	3	1,2,4-trimethylbenzene	6	7	66
tetrachloroethylene	2	12	15	butylbenzene, *n*-	2	5	5
trichloroethylene	1	3	3	chlorobenzene	1	10	10
styrene	10	6	45	propylbenzene, *n*-	2	8	10
toluene	14	9	222	xylene, *m*- and/or *p*-	8	6	44

the good lipid solubility of styrene (*37–39*). The total styrene intake has been estimated to be about 9 μg per day in the U.S. (*40*). The maximum value of styrene found in this study was 550 ppb in raw avocados. One would have to eat 16.4 g of avocados to produce 9 μg of styrene. However, it was estimated that more than 90% of human exposure to styrene and 99% of ethylbenzene are due to inhalation (*36*). Still, the International Agency for Research on Cancer (IARC) has classified styrene in Group 2B, possibly carcinogenic to humans (*41*).

Similar arguments can be made for toluene, the most abundant VOC. Although 1300 ppb was found in one cheddar cheese sample, inhalation is still the major source of human exposure. Dizziness and intoxication were reported in workers exposed to 40 ppm (40 000 ppb) for 6 h (*42*). There are few reports on oral doses of toluene, but in one unfortunate case, a mental patient ingested 60 mL (625 mg/kg), causing his death (*43*). A 70 kg man would have to eat over 56.875 million grams of the most contaminated sample of cheddar cheese given in **Table 2** found in this study to consume 43.75 g of toluene.

Similarly, inhalation is the major form of exposure to 1,1,1-trichloroethane. It has been estimated that average urban air has about 1 ppb and average human air intake is 20 m^3/day or 108 μg/day (*16*). One would have to eat 2117.6 kg of peanut butter containing 51 ppb of 1,1,1-trichloroethane to reach the 108 μg breathed in each day.

Chloroform is a probable human carcinogen with a potency factor of 1.97 mg/kg/day, placing it in Group B2 under EPA Guidelines for Carcinogenic Risk Assessment (*44*). Oral exposure of chloroform (dosed in corn oil) has been found to cause cancer in mice and rats (*45–47*). However, only 4 ppb of chloroform was found in olive/safflower oil (**Table 2**). A small, but statistically significant, increased risk of human cancers of the bladder, large intestine, and rectum associated with the presence of chlorinated compounds in drinking water have been reported (*48–56*). The risk assessments were difficult because of several factors: smoking, diet, air pollution, occupation, and lifestyle differences. The intake of other carcinogenic substances made it impossible to incriminate chloroform solely for the cause of increased incidents of cancer (*44*). Products in this study with the highest level of chloroform were dairy products: American cheese (54 ppb), cheddar cheese (107 ppb), cream cheese (100 ppb), butter (83 ppb), and sour cream (176 ppb). This has been seen in European dairy products, too (*57, 58*). It was shown to come from the use of fully automated cleaning and disinfecting (c&d) that used solvents containing active chlorine (*58*). The equipment was not disassembled, and the same c&d solvent was reused in a total recovery system in a pilot plant (*58*). This is also known as cleaning in place. When chlorine comes in contact with organic material in dairy products, chlorinated organic compounds or total organic chlorine is formed (*59–61*). This includes volatile organic chlorine (VOX) and non-purgable organic chlorine. The most important VOX is chloroform, which is formed by a haloform reaction (*62, 63*). The amount of chloroform was decreased 12.8-fold (to 1741 μg/L) by pre- and postrinsing with drinking water (*58*). Rinsing is required under German law, or LmBG 5 (*1*) No. 8, German Act for Foods and Objects of Daily Use (*64*) but is not required in the U.S.A. under CFR Title 21 Part 178 (*65*). The U.S.A. allows sanitizing with hypochlorite solutions up to a concentration of 200 mg/L or dichloroisocyurate up to 100 mg/L with adequate draining; rinsing is not required.

Another compound produced by the chlorination of water is bromodichloromethane (BDCM). The U.S. EPA has set a maximum contaminant level of 100 ppb for the combination of BDCM and similar compounds, the trihalomethanes (*54*). No more than 5 ppb BDCM was found in any food item tested in this study. Similarly, the U.S. EPA has set a maximum contaminant level of 100 ppb for chlorobenzene in drinking water. The most chlorobenzene found in a single food sample in this study was 51 ppb (in French fries). Little (<6 ppb) or none was found in the other foods. For carbon tetrachloride, a minimum risk level (MRL) of 0.02 mg/kg/day was established for oral exposure (*55*). A 70 kg man would have to eat 121.7 kg of bologna or beef frankfurters containing 11 ppb carbon tetrachloride to reach a daily dose of 1.4 mg. For 1,4-dichlorobenzene, a MRL of 0.4 mg/kg/day has been derived for intermediate duration (15–364 days) exposure. A 70 kg man would have to eat 95 890 kg of popcorn cooked in oil to reach a daily dose of 12 mg.

Thus, it can be concluded from data derived from the FDA's Total Diet Study that the American food supply is comparatively safe. Although there is some oral exposure to VOCs, they are usually inhaled at much higher doses through cigarette smoke, gasoline fumes, and industrial pollution (*9, 36*). The FDA continues to monitor foods for the presence of these compounds.

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